OKLAHOMA STATE UNIVERSITY

AND

UNIVERSITY OF ARKANSAS

COOPERATIVE REPORT ON

EVALUATION AND ASSESSMENT OF FACTORS AFFECTING WATER QUALITY OF THE ILLINOIS RIVER IN ARKANSAS AND OKLAHOMA

August, 1991

FINAL DRAFT

ON

EVALUATION AND ASSESSMENT OF FACTORS AFFECTING WATER QUALITY OF THE ILLINOIS RIVER IN ARKANSAS AND OKLAHOMA

TO

ENVIRONMENTAL PROTECTION AGENCY
REGION VI
ALLIED BANK TOWER AT FOUNTAIN PLACE
1445 ROSS AVENUE
DALLAS TX 75202-2733
PROJECT COORDINATOR: CHERYL OVERSTREET
(214) 655-7154

FROM

CO-PRINCIPAL INVESTIGATORS

OKLAHOMA STATE UNIVERSITY

STILLWATER OK 74078
Sterling L. Burks, Director
Sterling L. Burks
Water Quality Research Lab
(405) 744-5551

David Francko, Director
D. A. Francko
Arts & Sciences Research

Jerry Wilhm, Head
Jerry Wilhm
Department of Zoology

UNIVERSITY OF ARKANSAS

FAYETTEVILLE AR 72701
Richard Meyer
Richard L. Meyer
Department of Biological Sciences
(501) 575-4403

Arthur Brown
A. V. Brown 6 Aug 1991
Department of Biological Sciences

David Parker
David A. Parker
Department of Civil Engineering

Reference

Brown, A.V., S.L. Burks, D. Francko, R.L. Meyer, D. Parker and J. Wilhm. 1991. Evaluation and Assessment of Factors Affecting Water Quality of the Illinois River in Arkansas and Oklahoma. A Final Report to the U.S. E.P.A. Region VI, Dallas, Texas. 157pp. + Appendices A - K.

INTRODUCTION

As stated in Objective III, the data available did not indicate a general decrease in water clarity for the river. Clarity was poor and probably decreasing 1) in and below Lake Frances near the state border, 2) along Oklahoma Highway 10 where canoeing has become very intense, and 3) below the Tahlequah, Oklahoma sewage treatment facility effluent. The causes of decreases in water clarity at these specific sites seem obvious although cause and effect relationships are sometimes difficult to establish beyond any doubt. Lake Frances was (it no longer exists) an area where the flow diminished, which encouraged development of planktonic algae that probably contributed much of the turbidity. The convenience of having a good highway adjacent to the stream between SR 4 and SR 5 (see map), encouraged the development of an industry based on canoeing and related activities (camping, picnicing, swimming, etc.) that have degraded the water quality in that reach. The sewage treatment facility for Tahlequah appears to be unfavorably altering the water quality, including clarity, of the river for several miles.

Other insults to the riverine environment can contribute to localized water quality problems within the basin and these could eventually coalesce to produce a massive general problem that would be detectable at numerous routine monitoring sites. These include:

1) gravel removal from within the stream banks,

2) overgrazing and allowing beef and dairy cattle access to large areas of stream banks and streams,

3) road construction and maintenance practices within the basin,

4) bridge construction practices which allow runoff from roads and fields to enter streams,

5) driving vehicles directly into and across streams, especially for loading and unloading canoes, loading gravel, building bridges, and agricultural access,

6) damage to or removal of riparian (streamside) vegetation which stabilizes stream banks, shades the stream and serves as a buffer,

7) cultivation (plowing or discing) of fields which are regularly flooded by the river,

8) excessive and/or improper application of animal wastes to pastures adjacent to streams,

9) improper siting, installation and maintenance of septic

Table 32. Trend tests of annual loadings of residue as total nonfilterable residue.

Station	Kendall Tau Test Statistic	Seasonal Kendall Test Statistic	Seasonal Kendall Sen Slope Estimate (kg//yr)/yr
USGS 07194800	0.862	2.160***	49658
USGS 07195000	-0.785	-0.857	-29252
USGS 07195400	1.410*	1.030	372250
USGS 07195500	0.368	0.886	407266
USGS 07196000	1.695***	2.166***	57300
USGS 07196500	1.675**	0.782	193819
USGS 07197000	0.667	1.407*	24428

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 95% confidence level

Quarterly averages used to calculate all statistics. The Kendall Tau Test was performed on deseasonalized data.

Phosphorous

* NOTE: The available data are not very appropriate for calculating annual loading rates of plant nutrients because they do not necessarily include storm runoff values. Occasional storm runoff events may have been sampled, but most of this was done without a meaningful plan that would allow useful interpretations of the results. Most loading occurs during storm events. The following calculations for loading rates and associated modeling were conducted by Dr. Burkes and do not reflect the interpretations of all the other researchers.

The annual loading rate for total phosphorus(P) was calculated by multiplying concentration (mg/l) for a particular day by daily discharge (cfs) and converting the product to annual loading (kg/yr). The annual loading value for each sampling period was then used in WQSTAT to calculate seasonal means, medians, 25%, and 75% distribution for trend analyses on the annual loading values. The summary statistics for annual loadings indicate a decrease from USGS 07195500, below Lake Frances, when compared to USGS 07196500 located several miles downstream (Table 33). This decrease occurred even after additional loading was contributed from the

Flint Creek drainage basin, USGS 07196000.

The sampling stations and point source discharges with adequate records were used to calculate quartile distributions of annual loadings of total phosphorus (Table 34). The calculated annual loadings were then used to calculate the annual loading at Horseshoe Bend area, located just above Lake Tenkiller. This was assumed to be equal to the sum the loading at USGS 07196500 plus the contribution from Tahlequah STP plus the loading from Baron Fork (USGS 07197000), minus a correction factor for the average loss of phosphorus per mile of river flow (0.0017 mg/l/mile). Raw data was not readily available for the three Arkansas STP's included in Table 34 so we used total P loading data calculated by Walker (1987) for these point source discharges. Walker derived loading values based on monitoring data for 1986. These loading values were adjusted using the correction factor described above.

The calculated annual loadings for each sampling period were also subjected to trend analysis in WQSTAT to determine if there were longterm temporal tendencies. Quarterly averages were calculated from the monthly sample annual loadings and subjected to the Kendall Tau Test. The data were also corrected for seasonal trends to determine if there were significant temporal changes over time. The upstream stations (USGS 071964800 and USGS 07915400) above Lake Frances, showed significant increases over the period of record (Table 35). The stations on Flint Creek (USGS 07196000) and Baron Fork Creek showed a significant increase in annual loading rate of total P. Both mainstem Illinois River gaging stations : Oklahoma (USGS 07195500 and USGS 07196500) showed highl, significant increases in total P loading.

Analysis of the annual loading of phosphorus for long term trends indicated a significant increase when comparing the earliest with the recent records (Table 36). For example, the median annual phosphorus loading at USGS 07194800 during the period from 1975-80 was significantly (p=0.05) less than the period from 1981-86, estimated difference in medians was 1,408 kg/yr. Similar trends of increase in annual loading rates were detected at USGS 07196000, i.e., a significant increase of 9,177 kg/yr in median annual loading when comparing the period of 1979-82 and 1983-86 (Table 36). The USGS 07196500 records also showed a significant increase from 1977-81 vs 1982-86 of 34,775 kg/yr of annual phosphorus(P) loading.

The calculated annual loading values for the Illinois River at the Horseshoe Bend area (river mile 46.1) were used to calculate the appropriate total phosphorus(P) loading for graphical illustration of the eutrophication potential via Vollenweider's Index (Fig. 62). The mean hydraulic residence time was based upon 0.25, 0.50, and 0.75 quartiles distribution of lake level; i.e., lake volume, for each year calculated. The quartile distributions of the discharge were used as measures of the annual inflow for the respective lake levels noted above, i.e. .25, .50, and .75 quartiles of discharge were matched with the appropriate lake levels.

The phosphorus loadings to Lake Tenkiller in 1986 were obviously ranked in the eutrophic categories by the Vollenweider index (Fig 62). The fact that the 0.25 quartile distribution of the phosphorus loading also was ranked as eutrophic, would thus indicate that the phosphorus loading would have to be rated as carrying excessive loadings more than 75% of the time during 1986. Similar loading of phosphorus occurred all previous years for which we had records (Figures 62, 63, and 64). There does seem to be a trend for the phosphorus loading to increase over time, with a greater percentage distribution exceeding eutrophication boundary conditions.

There has been some debate concerning the applicability of Vollenweider's Index of Eutrophication to manmade reservoirs and lakes occurring at southern temperate latitudes. However, Lake Tenkiller is or was a relatively clear and deep reservoir and thus may be more analogous to the deep-clear northern temperate zone lakes that Vollenweider used to develop his indices than to most of the southern reservoirs that tend to be shallow and relatively turbid. There has been some disagreement among the authors of this report regarding whether the Vollenweider Index is an acceptable index of eutrophication loading in Lake Tenkiller. It is certainly not applicable to any stream, and the principal focus of this study was on the Illinois River and its tributaries, not Lake Tenkiller.

During the period from 1980-83, some of the 0.25 quartile distribution of phosphorus would have been classified as mesotrophic, i.e., still excessive but not as deleterious to overall lake water quality as the eutrophic classification. A similar trend was also occurring in the period from 1976-79, at least some of the annual loadings would be classified as mesotrophic. However, the calculated loadings for greater than 50% of the time from 1976 through 1986 would be classified as eutrophic loading conditions. We can obtain an estimate of the necessary reduction in annual phosphorus loading that would be required to initiate restoration of Lake Tenkiller towards oligotrophic classification, by using the 0.25 quartile loadings from 1979. The loadings would have to be reduced by a minimum of 50% and as much as 80%, in order for the lower quartile of the annual loadings to be classified as mesotrophic. Obviously, the median and 0.75 quartile loadings would have be reduced even more. Since 1983, the 0.75 quartile distribution of annual phosphorus loadings have exceeded 100,000 kg/yr (Table 37). Therefore, the projected reductions for these years would be 90% or greater. There seems to be overwhelming evidence that the annual loading of phosphorus to upper end of Lake Tenkiller is excessive. The consequences of a continued increase in loading rates to Lake Tenkiller would be deleterious to long-term water quality conditions.

Most plant nutrient loading to this and many other streams occurs during rainstorms when the stream flow and turbidity also increases. During high flow and increased turbidity, algal production in streams is minimal. Therefore plant nutrients passing through the stream system are of little, if any consequence. The impact of these nutrients is on downstream reservoirs, not the stream ecosystem.

Table 33. Summary statistics for calculated annual phosphorus loadings in kg/yr as P for entire period of record.

Source	Annual Phosphorus(P) loadings, kg/yr			
	N	Mean	Median	SD
GS48	108	14,853	858	54,385
GS50	77	89,051	0*	162,133
GS54	48	146,535	50,800	218,942
GS55	170	159,464	42,000	504,577
GS60	99	23,961	5505	99,803
GS65	127	127,702	29,300	371,305
GS70	126	32,163	3,640	153,355
Tahl STP	14	17,520	17,225	5,908

* missing several years of data

Table 34. Calculated annual total phosphorus(P) loadings (kg/yr) for Illinois River for CY 1986.

		Percentile Distribution			
Location	Minimum	25%	50% Median	75%	Maximum
USGS 07194800	540	3,000	4,200	19,000	160,000
Rogers, Ark. STP			18,000		53,000
Springdale, Ark. STP			32,000		58,000
USGS 07195400	48,000	55,000	75,000	150,000	930,000
USGS 07195500	31,000	51,000	80,000	180,000	9,600,000
Siloam Springs, Ark STP	0.0		5,300		16,000
USGS 07196000	2,8000	12,000	14,000	26,000	3,800,000
USGS 07196500	20,000	51,000	91,000	260,000	5,800,000
Tahlequah, Ok STP	6	17,000	19,000	23,000	44,000
USGS 07197000	94	7,800	15,000	31,000	1,700,000
Horseshoe Bend of Tenkiller*	9048	49,677	92,901	215,865	6,575,389

* estimated as sum of USGS 07196500 + Tahlequah STP + USGS 07197000 minus correction in loss/mile of flow, calculated as 0.0017 mg/l/mile

Table 35. Trend tests, total phosphorus (as P) annual sample loading.

Station	Kendall Tau Test Statistic	Seasonal Kendall Test Statistic	Seasonal Kendall Sen Slope Estimate (kg/yr)/yr
USGS 07194800	2.444***	2.640***	611
USGS 07195000	1.392*	0.857	3181
USGS 07195400	1.910**	1.242	6162
USGS 07195500	2.035***	2.333***	2575
USGS 07196000	2.402***	3.777***	1804
USGS 07196500	3.510***	3.542***	9102
USGS 07197000	2.478***	2.297***	1013

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 95% confidence level

Quarterly averages used to calculate all statistics. The Kendall Tau Test was performed on deseasonalized data.

Table 36. Comparison of upstream vs downstream median loading total phosphorus (as kg/yr P).

Stations Compared Upstream vs Downstream or (Intervals)	Wilcoxon Signed Rank Test Test Statistic	Seasonal Hodges-Lehmann Est. of Differences in Medians Total P (as P) (kg/yr)
GS48 vs GS54	-5.655***	60212
GS48 (75-80 vs 81-86)	-2.784***	1408
GS54 vs GS55	-1.302*	-13600
GS54 (82-84 vs 85-87)	-1.988***	22400
GS60 (79-82 vs 83-86)	-4.918***	9177
GS65 (77-81 vs 82-86)	-4.594***	34775
GS55 vs GS65	4.168***	-15000

* = significant at 80% confidence level
** = significant at 90% confidence level
*** = significant at 95% confidence level

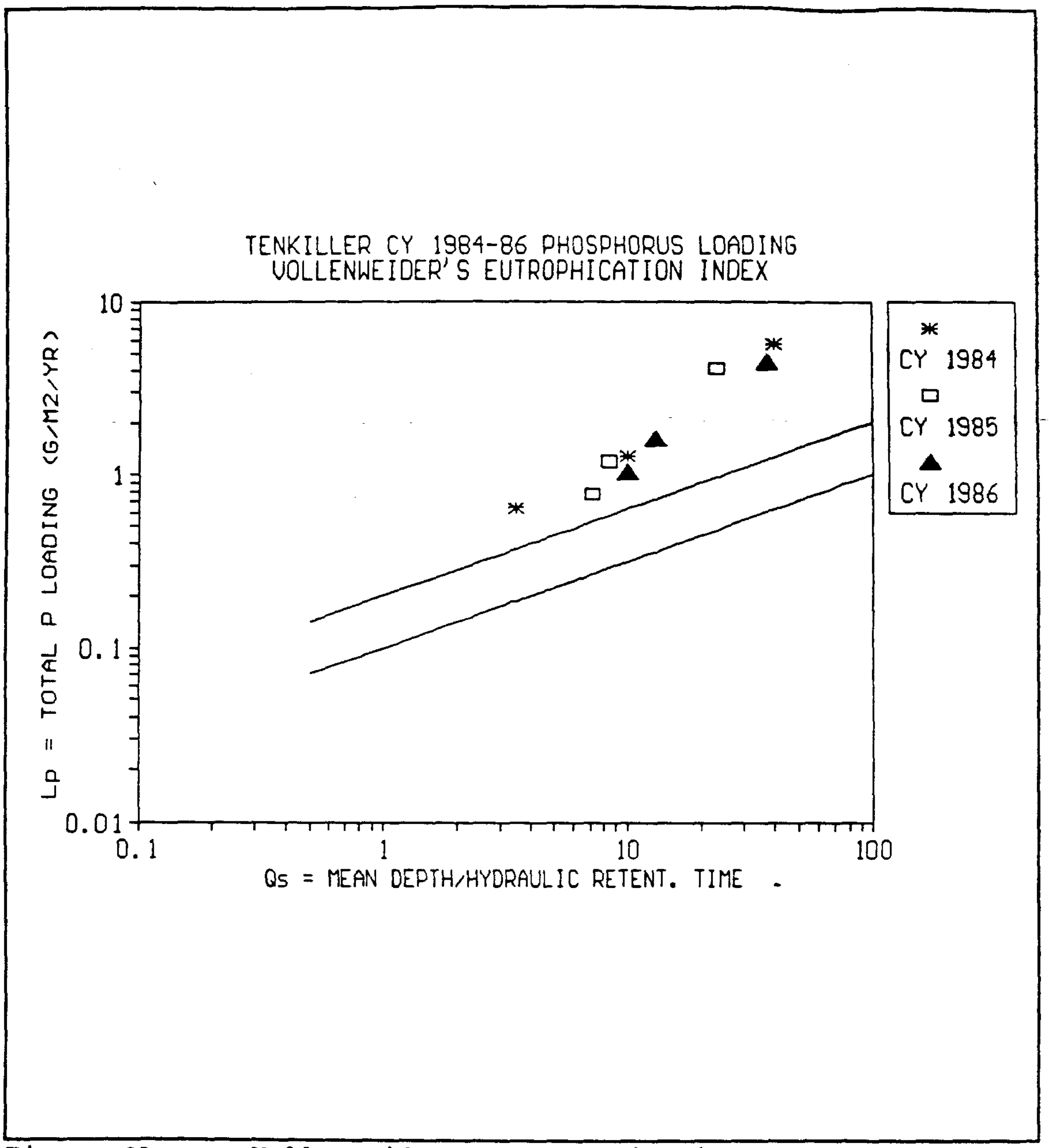

Figure 62. Vollenweider's Eutrophication Index for Lake Tenkiller for 1984-86 calculated for the 0.25, 0.50, and 0.75 quartile distribution of annual phosphorus(P) loading and volume inflow, respectively.

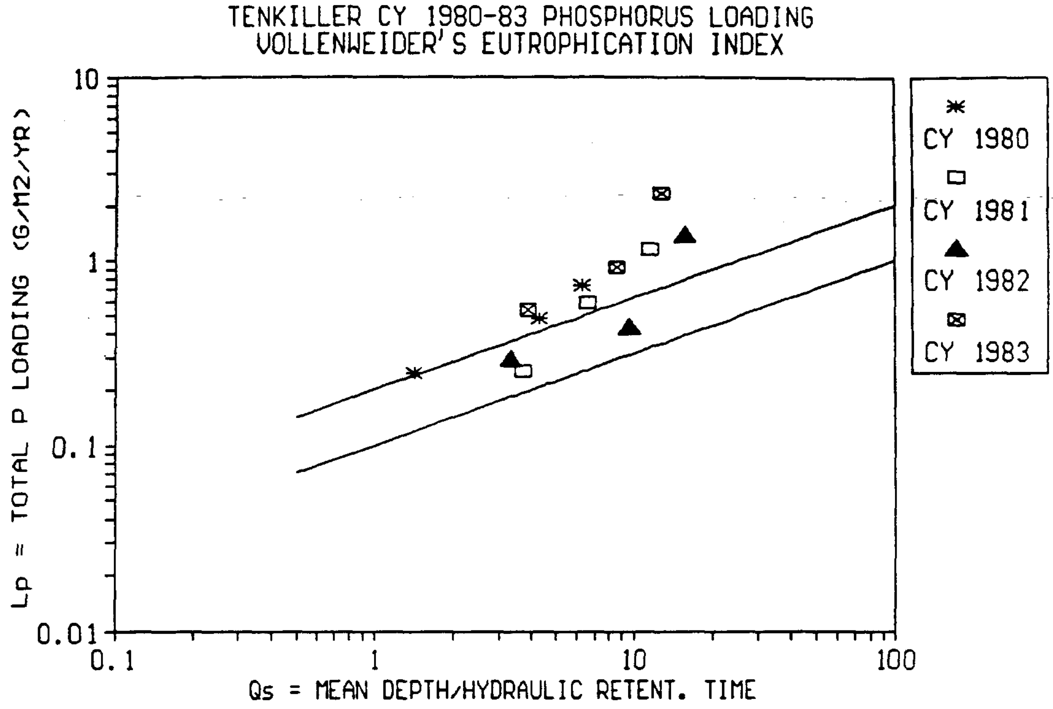

Figure 63. Vollenweider's Eutrophication Index for Lake Tenkiller for 1980-83 calculated for the 0.25, 0.50, and 0.75 quartile distribution of annual phosphorus (P) loading and volume inflow, respectively.

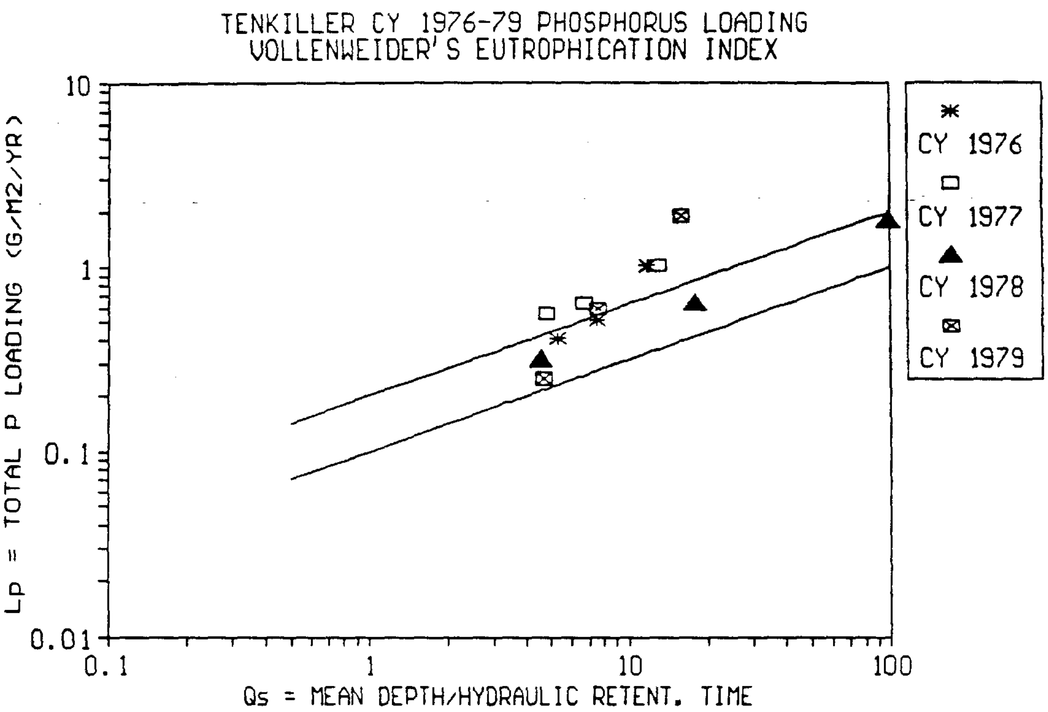

Figure 64. Vollenweider's Eutrophication Index for Lake Tenkiller for 1976-79 calculated for the 0.25, 0.50, and 0.75 quartile distribution of annual phosphorus(P) loading and volume inflow, respectively.

Table 37. Calculated Annual loadings of phosphorus as P at Horseshoe Bend Area of Lake Tenkiller, corrected for loss in miles of flow.

Calendar Year	Quartile Distribution of Loading kg/yr as P		
	0.25	0.50	0.75
1977	23321	32091	52524
1978	14852	32430	95476
1979	11822	30856	99432
1980	11370	23097	37297
1981	11841	29283	59643
1982	13787	22392	74119
1983	25431	48369	124744
1984	30962	66750	308260
1985	40569	64715	233113
1986	53887	84656	246561

Nitrogen

The annual loading for a specific sampling period was calculated by multiplying the mg/l concentration for a specific sampling date by the daily discharge (cfs) and an appropriate conversion factor to obtain kg/day. This value was then converted to an annual loading value by multiplying by 365 days/year. The sampling period annual loading value was then used in WQSTAT to obtain summary statistics of mean, median, and standard deviation of the sampling period annual loading values for the entire period of record. The mean annual loading of nitrite/nitrate as N in kg/yr showed an increase from the upper end (USGS 07194800) of 123,190 kg/yr to a peak concentration of 884,020 kg/yr at USGS 07195500, just below Lake Frances (Table 37). There was a decrease in mean annual loading of N from below Lake Frances to USGS 07196500.

There is no current agreement upon loading rates of inorganic nitrogen which are considered eutrophic. Inorganic nitrogen definitely contributes to growth of primary producers; however, the level that is considered excessive or that would promote development of undesirable species or densities of growth cannot be accurately defined. Sawyer (1947) suggested that concentrations of greater than 0.300 mg/l of total nitrogen and 0.010 mg/l of phosphorus at spring mixing would be conducive to development of eutrophic conditions. Vollenweider calculated and plotted the mean annual loadings of nitrogen in his classic study of over 200 lakes, but never attempted to develop an overall index based upon nitrogen loading. This is primarily because of the complications of interactions of nitrogen and phosphorus in promotion of algal growth. Although Vollenweider never attempted to develop a eutrophic index based upon nitrogen loading, his data may be useful for comparisons. Wetzel (1983) summarized Vollenweider's data into two major categories, permissible and dangerous loading for both nitrogen and phosphorus (Table 38).

We calculated the annual loading values projected to occur at the Horseshoe Bend area of Lake Tenkiller. The loading values were calculated by summing the annual loadings at USGS 07196500, USGS 07197000, and from Tahlequah STP and subtracting an average loss of 0.00907 mg/l/mile of flow. The annual NO_2/NO_3(N) loadings were calculated for the quartile distributions of both concentration and discharge for each year of record. The 0.25, 0.50, and 0.75 quartile distributions of nitrogen load were then graphed with respect to the projected mean lake level, i.e., power pool minus 25% volume lake level elevation (618 ft MSL) for the 0.25 quartile of discharge and nitrogen loading, power pool lake level elevation (632 ft MSL) for the 0.50 quartile distribution of discharge and nitrogen loading, and flood stage lake level elevation (667 ft MSL) for the 0.75 quartile distribution of discharge and nitrogen loading. Obviously, we had to make some arbitrary assumptions that greater discharge would transport higher loadings of nitrogen and would result in higher lake elevations and the converse of thi- relationship.

Table 38. Summary statistics for calculated annual nitrite/nitrate loadings for entire period of record.

Source	Annual NO2/NO3(N) loadings, (kg/yr)			
	N	Mean	Median	SD
USGS 07194800	96	163000	20100	246139
USGS 07195000	33	377724	0*	224096
USGS 07195400	55	1030478	63800	1050163
USGS 07195500	110	766045	169000	1644380
USGS 07196000	82	123207	30800	361764
USGS 07196500	96	807803	214000	1484658
USGS 07197000	98	246966	45700	444291

* missing several years of data

Table 39. Provisional permissible loading levels for total nitrogen and total phosphorus in $g/m^2/yr$.

	Permissible Loading		Dangerous Loading	
Mean Depth (m)	Total Nitrogen	Total Phosphorus	Total Nitrogen	Total Phosphorus
5	1.0	0.07	2.0	0.13
10	1.5	0.10	3.0	0.20
50	4.0	0.25	8.0	0.50
100	6.0	0.40	12.0	0.80

Modified from Wetzel (1983)

The projected loadings with respect to mean depth (m) provid an index of the relative potential of nitrogen to stimulate algai growth in Lake Tenkiller. The projected annual nitrogen loading during the four years from 1977 to 1980 indicates that nitrogen loadings would be rated excessive for all of the quartile distributions in 1977 (Figure 65). The plots indicate that more than half the nitrogen loading in 1978 and 1979 would be rated as excessive. The loadings in 1980 were not as excessive, with only the upper quartile exceeding the dangerous level suggested by Wetzel.

During the periods from 1981-84, the calculated annual NO2/NO3(N) loadings exceeded the permissible levels at all quartile distributions, except for the 0.25 distribution in 1981-1983 (Figure 66). The highest loadings occurred at the 0.75 quartile distribution during 1984. The annual NO2/NO3(N) loadings for 1985-1986 and for the entire period of record indicate a similar trend (Figure 67). However, due to high levels of discharge, the calculated loadings were much higher in 1985-1986 than in the previous years. When considered over the entire period of record from 1977-1986, the quartile distributions greater than 0.25 exceeded the suggested permissible loadings by factors ranging from 2X to 10X.

Based upon the indices of nitrogen loadings suggested by Wetzel, the Illinois River is transporting more than enough NO2/NO3(N) to stimulate excessive algal growth in Lake Tenkiller. We did not attempt to include ammonia or Kjeldahl nitrogen in t total nitrogen loading calculations, since there was a limiteu number of samples. However, if these additional forms of nitrogen were added to the calculated NO2/NO3(N), it would obviously increase the total annual loading even more.

More than 50% of the calculated annual loadings of both phosphorus and nitrogen exceeded established limits for development of eutrophic conditions in Lake Tenkiller. There can be little doubt concerning the long-term prospects for water quality in Lake Tenkiller, if this trend is not reversed.

Many authors have attempted to rate the relative contribution of nitrogen to development of eutrophic conditions on the basis of N/P ratios, since it has been well established that Liebig's Law of the Minimums is a controlling factor for algal growth. The N/P ratio is often used to determine which macronutrient may be the "limiting" factor for algal productivity. N/P ratios greater than seven to ten are often cited as indicative that phosphorus is the macronutrient limiting primary productivity. Conversely, N/P ratios less than seven may be interpreted to mean that nitrogen is the limiting nutrient.

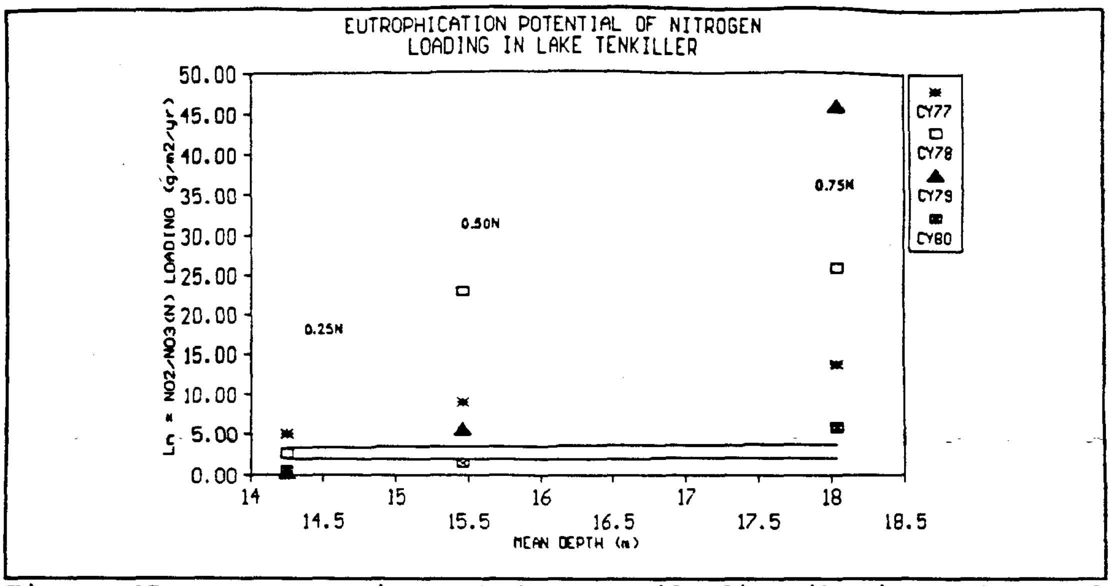

Figure 65. Comparison of the quartile distributions of annual nitrogen(N) loadings to Lake Tenkiller in CY 1977-80 with loadings suggested by Wetzel as dangerous or permissible.

We calculated the N/P ratios at two locations in the upper end of Lake Frances and at Horseshoe Bend, which is on the upper end of Lake Tenkiller (Table 40). Based upon these ratios, it would appear that phosphorus may be the limiting nutrient in Lake Frances, whereas nitrogen appears to be the limiting nutrient in Lake Tenkiller. However, these ratios obviously vary with the level of discharge and seasons of the year. The ratios should not be the primary factor in determining whether to focus all control measures on either nutrient alone. The concentrations of both nitrogen and phosphorus are excessive and should be reduced. If the concentrations of both nutrients could be reduced significantly, then perhaps a higher priority could be placed upon the nutrient most easily controlled and in the most economically feasible manner.

The long term trends in nitrogen loading at USGS 07194800 showed a significant increase of 15,943 kg/yr over the period of record (Table 41). The increase in loading rate was even greater at USGS 07195400, showing a significant trend of 71,933 Kg/yr. The overall trend for most of the main stem sampling stations was an increase for the period of record. These long-term trends could be

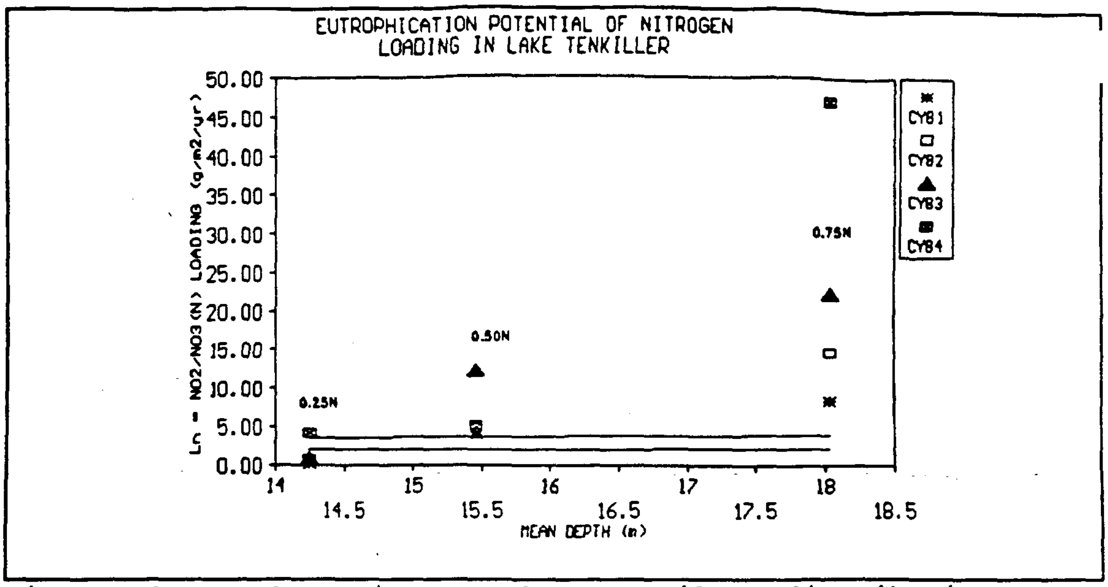

Figure 66. Comparison of quartile distributions of nitrogen(N) loadings to Lake Tenkiller in CY 1981-84 with Wetzel's suggested dangerous or permissible loadings.

interpreted to indicate that while there is an increase in nitrogen discharge to the upper portions of the Illinois River, the biota along the length of the river has assimilated most of the increase nitrogen. This should be reflected in greater densities of periphyton along the length of the river.

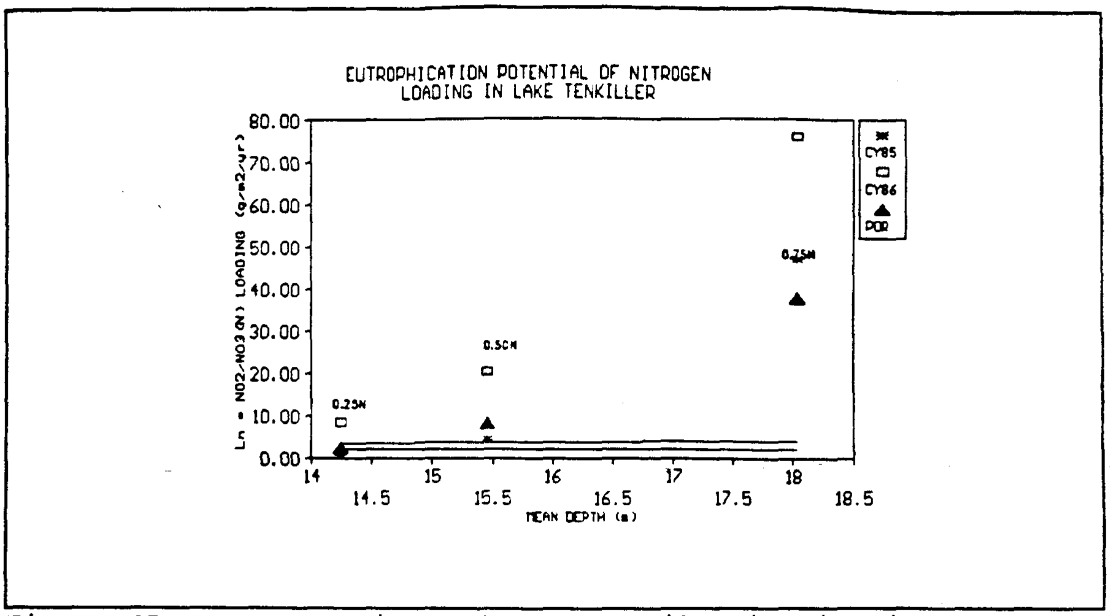

Figure 67. Comparison of the quartile distribution of annual nitrogen(N) to Lake Tenkiller in CY 1985-86 and entire period of record with Wetzel's suggested dangerous and permissible loadings.

Table 40. Calculated N/P Ratios for the quartile distributions of annual loadings at the upper ends of Lake Frances and Lake Tenkiller.

Calendar Year	Lake Frances N/P ratio			Lake Tenkiller N/P ratio		
	.25	.50	.75	.25	.50	.75
1977	---	---	---	6.9	11.1	12.3
1978	---	---	---	6.7	28.2	22.0
1979	---	---	---	3.3	8.3	19.0
1980	---	---	---	2.1	3.7	7.5
1981	4.6	5.8	7.7	2.4	6.4	7.2
1982	4.2	3.6	9.7	2.9	11.6	9.7
1983	4.6	5.7	7.1	1.9	9.9	7.7
1984	4.3	17.3	5.1	4.2	3.8	7.2
1985	6.2	16.9	11.0	1.8	3.4	8.7
1986	7.4	12.5	11.5	5.4	9.4	13.3
1987	7.4	8.5	17.6	---	---	---

Table 41. Trend tests, NO2+NO3-N annual sample loading

Station	Kendall Tau Test Statistic	Seasonal Kendall Test Statistic	Seasonal Kendall Sen Slope Estimate (kg/yr)/yr
USGS 07194800	3.266***	2.526***	14604
USGS 07195000	0.183	0.000	-208
USGS 07195400	2.059***	2.130***	49167
USGS 07195500	0.955	0.912	22477
USGS 07196000	2.588***	2.814***	18473
USGS 07196500	1.906**	1.867**	36058
USGS 07197000	1.186	0.733	4605

Quarterly averages used to calculate all statistics. The Kendall Tau Test was performed on deseasonalized data.

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 95% confidence level